Horizon scanning the European bio-based economy

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Perspective

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Horizon scanning the European bio-based economy: a novel approach to the identification of barriers and key policy interventions from stakeholders in multiple sectors and regions

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Abstract: There is international recognition that developing a climate-smart bioeconomy is essential to the continuation of economic development, reduction of greenhouse gas emissions, and adaptation to climatic change; Bio-based products have an important role in making this transition happen. Supporting policy interventions have been put forward at European and national levels to support innovation and development of bio-based products and services. This study asks whether suggested policy interventions reflect the needs of stakeholders and examines how these needs vary between European regions. This consultation was performed through an online survey of 447 experts actively involved in bio-based research, industry, and governance across Europe. The majority of responses received were from stakeholders in France, Germany, Italy, Spain, and the UK which are examined in greater depth.

Climate change was clearly an important driver for bio-based innovation as 86% of the respondents considered climate change to be a significant threat. There were clear differences between regions

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but also areas of consensus between stakeholders across the European regions surveyed. In particular there was consensus regarding the need for improved access to financial support and the need to ensure continuity of policy. The need to build investor confidence through demonstration of bio-based technologies, the provision of greater clarity regarding best conversion routes for specific feedstocks, and the need to promote a culture of industrial symbiosis were also regarded as important interventions.

Keywords: bioeconomy; bio-based; max-diff, best-worst; biorefining; innovation system

Introduction

The global bioeconomy is on the brink of renaissance as bio-based resources and processes are sought to replace or reduce those currently derived from fossil sources. Many policies in Europe, the USA, China, Brazil, and other regions call for development and deployment of alternative bio-based industrial processes, technologies, and products to de-carbonize manufacturing processes and product streams.[1-4] In Europe, the bio-based economy is still in an early stage of development and there is a considerable lack of information regarding new bio-based sectors and markets compared with other more established industries.[5] Development and upscaling of the new bio-based industry is underpinned by the need to stimulate innovation and entrepreneurial activity to generate wealth and create jobs whilst ensuring that large-scale and stable supplies of biomass are sustainably managed.[6] All of these challenges require public sector intervention to achieve. To address these challenges, a number of reports and roadmaps have been commissioned across Europe to map the current economic landscape, identify areas of best practice and the main barriers to growth, and suggest policy interventions which would best support innovation and economic growth.[4,7–10]

The Star Colibri FP7 project, a collaborative initiative on biorefineries, linked European technology platforms and major research centers to deliver the first comprehensive list of obstacles and priorities for policy intervention in the bio-based economy.[11] This was followed by the European Commission appointed 'ad-hoc advisory group for bio-based products' in the framework of the European Commission's Lead Market Initiative (LMI) which published an initial report and delivered a number of priority recommendations exploring more demand-side innovation.[12,13] Both of these initiatives subsequently fed into the development of the current European Bioeconomy Strategy, and led to the development of several 'innovation partnerships' and the creation of an expert group for bio-based products to monitor and support development of the policy framework.[9,14] More recently the EU-funded project BIO-TIC provided a list of recommendations based on a large campaign of workshops and expert interviews.[15] A comparison of the key findings and interventions suggested by these reports is presented in Table 1.

These scoping studies and stakeholder consultations were performed to help guide bio-economic policy; however, as these studies were developed independently, their results are difficult to collate, compare, and utilize in a complementary way. [7,8,15] This presents problems when attempting to use the information to inform policy, particularly at a European level, as it is difficult to assess differences between regions and sectors regarding the main barriers to growth.

In 2013 the European Commission initiated a Bioeconomy Observatory initiative led by the Joint Research Centre (JRC) to address the issues surrounding the availability of complementary information and provided an open access repository of documents related to bioeconomy research, markets, and policies from multiple countries. While this is an excellent resource for retrospective analyses, information from different stakeholder workshops or surveys remains difficult to compare and the effects of specific policy interventions are difficult to identify and measure over time. To overcome this problem a common design or framework for constructing such analyses is required to allow results from separate studies to be more readily comparable and provide a better opportunity for long-term investigation and monitoring. In this paper we propose the use of an innovation systems approach to provide a common framework for design and comparison of such consultation studies.

A number of frameworks are frequently used in strategic and market analysis to examine the effects of

Table 1. Interventions suggested by key consultation studies required to support growth of the European bio-based economy.

	Star Colibri (2011)[11]	Lead Market Initiative (2011)[12]	BIO-TIC (2015)[15]
Knowlevvdge development	• Support key enabling technologies	• Enhance technological innovation	• Investigate the scope for using novel biomass • Improve the bioconversion and down-stream processing steps
Knowledge exchange	• Encourage stakeholder engagement between bioeconomy sectors • Support cooperation between aca-demia and industry (Public Private Partnerships) • Encourage big companies and SMEs to work together	• Achieve coherent messages on bio-based products	• Develop stronger relationships between conventional and non-conventional players
Guidance of the search	• Reduce duplication of effort and frag-mentation of research funding within the EU • Develop holistic approach for the EU policy landscape	• Encourage contracting authorities in EU member states to give preference to bio-based products in tender specifica-tions (*Green Public Procurement*) • Balance of legislation and policies between bioenergy and bio-based products • Continue to develop and apply clear European and international standards • Consider setting indicative or binding targets for certain bio-based product categories • Promote and use harmonized certifi-cation and labelling schemes for bio-based products	• Promote the use of co-products from processing (*Industrial symbiosis*) • Introduce a long-term, stable and transparent policy and incentive frame-work to promote the bioeconomy*
Resource mobilization	• Improve the attractiveness of this sec-tor through education and training • Ensure access to consistent quality feedstock in sufficient quantity, at a competitive price • Fund new product development	• Promote the availability of feedstocks at competitive price • Set up a specific EU Innovation Fund • Open Structural Funds to bio-based products • Increase public funding for demon-stration projects via public-private partnerships	• Improve opportunities for feedstock producers within the bioeconomy • Develop a workforce which can main-tain Europe's competitiveness in indus-trial biotechnology • Improve access to financing for large-scale biorefinery projects
Resistance to change	• Attracting investors to the end of the biorefinery value-chains • Fund biorefinery demonstration plants, up-scaling facilities and activities	• Develop incentives for the conversion of production plants and industrial pro-cesses to support the development of bio-based products	• Improve public perception and aware-ness of industrial biotechnology and bio-based products • Identify, leverage and build upon EU capabilities for pilot and demonstration facilities

Précis of recommendations from previous studies grouped acording to innovation system functions as applied in this study. *Also relevant to counteracting resistance to change – for example ensuring continuity of policy.

macro-environment externalities. Frameworks commonly used for this purpose include aggregation by factors of political, economic, social, or technological influence (PEST) and now frequently also involve inclusion of environmental (STEEP) and legal factors (PESTLE). These frameworks may be employed to aggregate and analyze factors which can be assessed in terms of strengths, weaknesses, opportunities, and threats (SWOT). The development of the bio-based economy, however, involves a deeply interconnected series of actors and value chains operating at international, national, regional, and sectoral levels as well as different spatial scales all developing in parallel

with innovations in enabling technologies. For this reason many of these existing frameworks may be too simplistic to capture the information required and be reliably deployed in multi-regional and longitudinal analyses of the bio-based economy. Therefore a systems approach to analysis and interpretation is more appropriate.

Innovation Systems (IS) frameworks can be applied to study National (NIS), Regional (RIS), Sectoral (SIS), or Technical (TIS) innovation systems. Until recently these frameworks were focusing on system structure or components (e.g. institutions involved), but since the publication of Hekkert *et al.* (2007) the importance of system functions has been emphasized.[16] The goal of any innovation system is to generate and diffuse innovations which lead to technological change.[16] These innovations consequently result in degrees of socio-economic and political change which form part of a dynamic and constantly evolving system. Therefore, such systems are best defined in terms of knowledge or competence flows rather than ordinary goods and services and better characterized by investigation of the networks actively involved in the processes.[17]

Innovation system analysis methodologies along with other heuristic analyses are not rigidly defined and there is still much discussion regarding their definition, application, and measurement.[18,19] It was not the intention of this study to conduct a full innovation system analysis on the technologies or regions involved, although the data generated may prove useful as a guide or adjunct to subsequent innovation studies. Instead, system functions were used to provide a pragmatic framework to investigate the structure and function of the 'living' system through evaluation by key stakeholders and experts active within the innovation system(s) under scrutiny.[20,21] This paper presents the results of a bio-based economy stakeholder consultation study conducted by online-survey which employed innovation system functions as a framework for its design and interpretation.

Methodology

Goal and definition of scope

The primary objective of the survey was to assess the relative merit of a number of proposed policy interventions which have been suggested to support growth in the European bio-based economy. The list of interventions was determined through process of elimination based on results of previous consultation studies and dialogue with experts in the field (Table 2).[4,7,9,10,12,13] Secondary objectives were to assess the degree of consensus and disparity within and between European regions, stakeholder groups, and industrial sub-sectors. Main stakeholder groups comprised the 'triple helix' of actors from research, industry, and policy. Actors involved or related to white, green, and blue bio-technologies and their supply chains were the initial target audience used in survey design, early trials and distribution. This target audience was selected as it represented key areas of high-knowledge content and innovation within the bio-based economy.

Survey design

The survey was composed of two sections: The first part collected demographic information about the respondent which included: region of origin; stakeholder group (academic, industry, policy); organization type and main activities; company size and maturity (years trading); and details of feedstocks and products used or made.

The second part of the survey collected stakeholder opinion regarding the relative importance of policy interventions presented using a pair-wise comparison method referred to as best-worst or maximum difference scaling (max-diff).[22] Innovation system functions as described by Hekkert *et al.* were used as a framework to aggregate interventions to be incorporated into max-diff survey design (Table 2).[16] The 'Entrepreneurial activities' function was not included in the max-diff section as this was accounted for by questions in the demographic section. Intervention statements were randomized and presented to the respondents in multiple sets of five from which they were asked to repeatedly select the 'most beneficial' and the 'least beneficial' of the interventions shown. This was repeated with different sets of five until each individual comparison had been presented three times. The max-diff method was selected as it provided a robust statistical methodology which also offered a rapid and user-friendly means of data collection and management via online survey. The multiple comparison approach was also selected to reduce scale bias and issues associated with cross-national differences in perception of ratings scales which have been highlighted in previous studies of this type.[23,24]

Survey distribution

The survey was developed and hosted online using Sawtooth Software Inc., MaxDiff SSI Web survey utility.[22] The survey was launched online in Europe in June 2014 in five languages (English, German, French, Spanish, and Italian) and disseminated by e-mail invitation and social media channels to respondents via bio-based economy associated contacts, networks, and associations, first

Table 2. Interventions presented in the survey grouped by innovation system function*and the top five selected as most important by respondents from the main study regions.

TIS*	No.	Intervention:	FR	DE	IT	ES	UK
Knowledge development	1	Improve access to pilot facilities					
	2	Identify and address knowledge gaps			•		
	3	Establish best conversion routes for biomass type	•	•			
	4	Promote access to intellectual property					
Knowledge exchange	5	Facilitate business to business collaboration					
	6	Further academia to business collaboration	•		•		
	7	Develop international networks or clusters					
	8	Develop regional networks or clusters					
Guidance of the search	9	Boost engagement with policymakers				•	
	10	Institute standards and regulations for the bioeconomy		•			
	11	Stimulate industrial symbiosis	•	•	•		
	12	Advocate use of standardized life cycle analysis					
Market formation	13	Build stakeholder consensus on bioeconomy development					
	14	Implement green public procurement					
	15	Champion utilization of local resources					
	16	Create conditions for niche markets					
Resource mobilization	17	Develop a skilled workforce					•
	18	Provide access to financial support			•	•	•
	19	Stable feedstock supply					
	20	Ensure competitive feedstock costs					
Resistance to change	21	Ensure continuity of policy			•	•	•
	22	Build investor confidence in the bioeconomy	•	•		•	•
	23	Raise public awareness of bio-based products				•	
	24	Promote demonstration of technologies and products	•	•			•

*Innovation system functions as defined by Hekkert *et al.*[16]

within the Climate KIC network in initial survey trials and subsequently broadcast more widely. A database of networks and stakeholders involved in the bio-based economy was prepared by project partners in each region and the link to the questionnaire together with a brief explanation of the project objectives was sent via e-mail in the respective language.

Data collection and analysis

Following data collection, a hierarchical Bayes (HB) using a multinomial logit analysis (MNL) model was used to estimate individual-level (MaxDiff) scores.[25] Further statistical analysis was performed using IBM SPSS statistics V22. Multivariate general linear analyses of variance (MANOVA) were performed to identify significant differences between factors and where appropriate, Student-Newman-Keuls (SNK) post-hoc multiple comparisons were applied ($P \leq 0.05$). Statistical analysis was only performed on the data from France, Germany, Italy, Spain, and the UK where responses were sufficient in number and balanced between stakeholder groups.

A total of 447 credible responses from European regions were given to part 1 of the survey, 331 of which completed

both part 1 and part 2 (Table 3). The difference in numbers is two-fold: first, due to drop-out or incomplete response to the max-diff section; second, the questions in the max-diff section were replicated and inconsistent responses were detected and eliminated during the HB-MNL data processing. To clarify: inconsistent responses are here defined as situations where no discernible pattern to the responses was identified which meant the respondent was checking boxes at random rather than giving considered and genuine responses to the max-diff section on the online survey program. Identification of such responses is an important feature afforded by this type of online survey design.

Results and discussion

Respondent demographic

Of the 331 complete responses, academic, industrial, and policy stakeholders comprised 111, 132, and 88 responses, respectively. A greater number of responses were received from the main regions of focus namely: France, Germany, Italy, Spain, and the UK which collectively provided 257 responses and a balance of academic (32%), industrial (37%), and policy (31%) stakeholders. The total number of respondents and relative proportions of stakeholder groups (academic, industrial, policy) are given for each region and region group (Table 3). The numbers in parentheses indicate the number of respondents who completed both parts of the survey and whose responses were included within the calculation of max-diff loading scores and subsequent analyses.

Academic and policy expert respondents were predominantly from science and technology backgrounds; 78% and 82%, respectively. The remaining 18–22% were associated with related fields of economics, business innovation, law and public policy. Policy respondents were predominantly employed by industry associations or networks, government agencies, or local/regional government, collectively these accounted for 71% of the policy respondent organizations.

Table 3. Responses to Biohorizons survey by stakeholder group and region.

Region	Academic		Industry		Policy		Total	
High-response regions								
France	16	(15)	18	(11)	21	(17)	55	(43)
Germany	31	(26)	34	(21)	16	(13)	81	(60)
Italy	14	(12)	16	(13)	20	(17)	50	(42)
Spain	10	(6)	30	(23)	12	(10)	52	(39)
UK	30	(27)	42	(26)	36	(20)	108	(73)
Sub total	**101**	**(86)**	**140**	**(94)**	**105**	**(77)**	**346**	**(257)**
%	29	(33)	40	(37)	30	(30)		
Other European regions								
Other EU	**33**	**(25)**	**49**	**(38)**	**19**	**(11)**	**101**	**(74)**
Austria	1	(1)	4	(3)	1	(1)	6	(5)
Belgium	2		6	(5)	8	(5)	16	(10)
Hungary	14	(11)	11	(10)	7	(3)	32	(24)
Ireland			1	(1)			1	(1)
Netherlands	1	(1)	11	(9)			12	(10)
Portugal	2	(2)					2	(2)
Switzerland	1		4	(2)			5	(2)
Denmark	8	(6)	4	(3)	1	(1)	13	(10)
Finland			3				3	
Norway			1	(1)	1		2	(1)
Sweden	4	(4)	4	(4)	1	(1)	9	(9)
Total EU	**131**	**(111)**	**189**	**(132)**	**127**	**(88)**	**447**	**(331)**
%	**29**	**(33)**	**42**	**(40)**	**28**	**(27)**		

Industrial respondents were mainly involved in technology development (25%), knowledge transfer (20%), and manufacturing (19%). Service providers, independent R&D businesses, and primary producers made up the remainder comprising 15%, 13%, and 9%, respectively. Retailers represented only 1% of the total. The bulk of the responses in these regions were therefore predominantly supply-side actors; however there was also good representation from respondents involved in knowledge transfer and consultancy organizations who should be well placed to provide a degree of demand-side perspective. In terms of business size, 40% of industry respondents were micro companies, 40% small and medium enterprises (SMEs), 7% large, and 13% large multinational firms.

Within regions, SMEs constituted the greater proportion of responses from Germany, France, and the UK, whereas micro-companies constituted the majority of respondents from Spain. Large and large multinational companies constituted a small proportion of responses from most countries; however in the UK no large national company responses were received, only large multinational. These responses correspond with the details given regarding length of time trading in bio-based industry. Overall 34% of businesses had been trading for over ten years, 30% for 5–10 years, 17% for 1–5 years, and 18% for less than one year. This implies there is certainly a considerable degree of entrepreneurial activity ongoing; however it is perhaps not an area attracting a great many start-up companies based on these results. In the case of Spain and Germany however, there was a substantially greater proportion of micro-companies and SMEs which began trading within the last five years (since 2009) which may suggest some form of additional impetus in those regions.

In terms of feedstock and products, on average conventional crops (including forest) and crop residues each accounted for 23% of the total feedstock used by industry respondents, dedicated energy crops made up 17% of the feedstocks used by industry respondents, industrial wastes and co-products comprised 18%, marine biomass 7%, and 12% were other feedstocks largely intermediate biorefinery products such as plant fibres, botanicals, or pre-treated lignocellulose streams (Fig. 1). Some regional differences were observed: respondents from Italy and Spain cited a higher proportion of industrial wastes and co-products (27% and 21%) than conventional crops (11–15%) used as feedstocks.

Bio-based products manufactured by industrial respondents were predominantly fuels (21%), food or feed additives (18%), bulk chemicals (16%), and bio-plastics/polymers

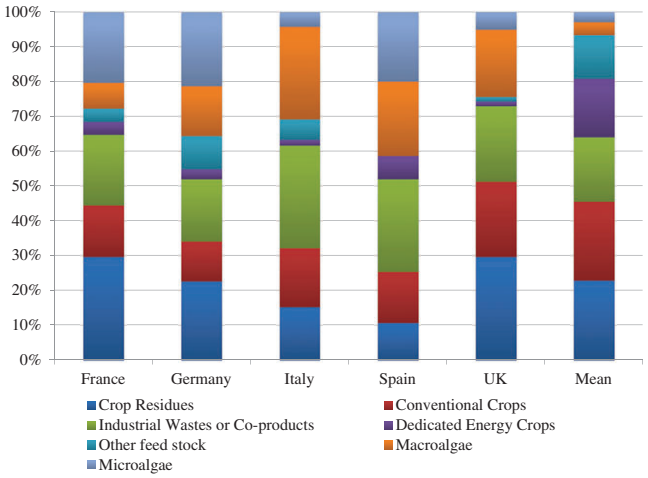

Figure 1. Feedstocks used in bio-based products by responding businesses expressed as a percentage of the total number of respondents within each region.

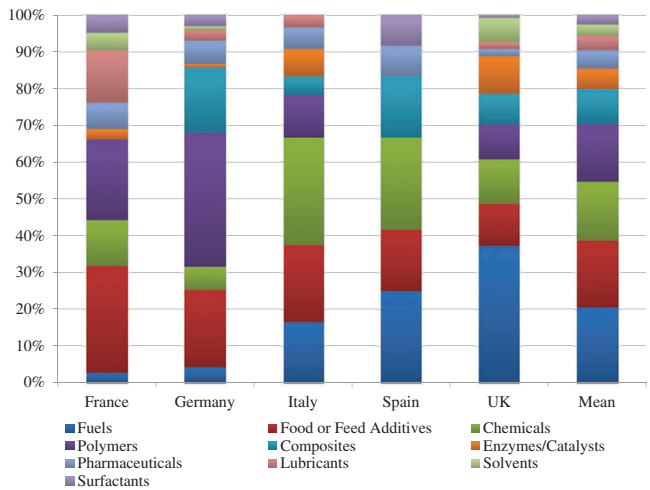

Figure 2. Supply-side respondents: Bio-based products produced by responding businesses expressed as a percentage of the total number of respondents within each region.

(16%) (Fig. 2). Enzymes and catalysts, one of the main enabling technologies of bio-based manufacture, accounted for 6% of the bio-based products produced by respondents.

To reflect also the demand-side perspective, respondents were also asked which bio-based products they required/used. As would be expected, the demand reflected supply with fuels (23%), enzymes and catalysts (17%), food or feed additives (14%), bulk chemicals (13%), and biocomposites (12%) cited as the main bio-based product used (Fig. 3).

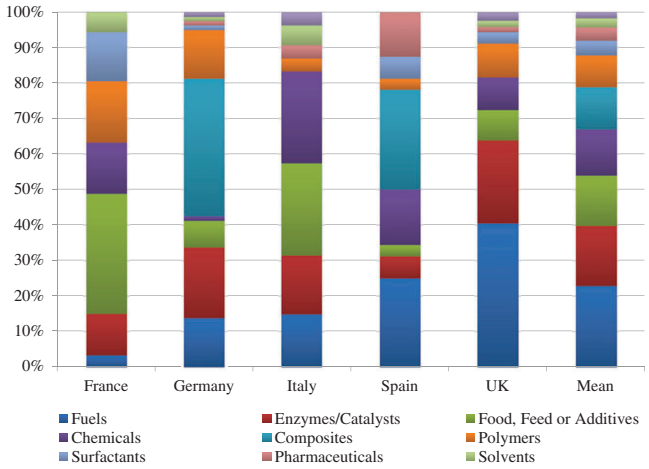

Figure 3. Demand-side respondents: Bio-based products used by responding businesses expressed as a percentage of the total number of respondents within each region.

Key barriers and the interventions needed to overcome them

Regarding one of the most significant and overarching barriers, one of the first questions stakeholders were asked was whether they thought their organization would be affected by climate change: 87% of respondents did consider climate change to be a genuine threat.

Based on responses received from France, Germany, Italy, Spain, and the UK the main perceived barriers to development of a climate-smart bio-based economy were establishing legitimacy of bio-based alternatives, combating the resistance to change, and mobilizing the required resources to support growth. Table 2 and Fig. 4 summarize the main overall differences between perception of barriers and suggested interventions by stakeholder groups study regions. Figures 5(a) to 5(e) summarize responses for each of the main study regions and significant differences of stakeholder perceptions within each region.

Between stakeholder groups (academic, industrial, policy) significant difference between the perceived levels of importance was observed for only a small number of specific interventions (Fig. 4). Academic respondents placed greater importance on the need to address knowledge gaps and stimulate industrial symbiosis than industry or policy stakeholders. Industry stakeholders placed greater importance on aspects of financial support, feedstock cost, and conditions for niche markets than the two other groups (Fig. 4). These overall results reflect differences in the perspectives of the stakeholder groups which could be described as aligned with their role within the innovation system: industry, finance and markets; academic, knowledge development, and systems thinking; policy, communication, and linking actors within the innovation system.

Overall, access to financial support and ensuring continuity of policy could be considered amongst the most important interventions overall as evidenced by the comparably high max-diff scores and also the smallest degree of variation (error bars) which means both interventions were consistently ranked by all stakeholder groups across all regions (Fig. 4).

It should however be noted that all interventions presented in the survey were selected based on results from previous research and/or expert dialogue. Therefore, a low comparative ranking in this survey does not suggest a lack of importance, simply that other interventions were considered to be more immediately beneficial by survey respondents at the time of completion.

Interventions presented within the function of **knowledge development** were selected to address whether respondents felt significant knowledge gaps existed; whether the knowledge was already developed but access to that intellectual property (IP) was an issue; and another two factors frequently cited as issues: knowledge of best conversion routes for certain biomass types and availability/access of pilot facilities required to take bio-based technologies/products and businesses to the next level.

As a largely knowledge-driven sector, development of knowledge was not considered a major barrier and access to IP was considered amongst the least important interventions included in the survey. Knowledge development also received fewer recommendations in previous studies most of which were focussed on improvements to enabling technologies and their efficiency (Table 1). There were clear differences in perception between countries in this study but these were most likely associated with differences in technological emphasis rather than differences in national policies.

Concerning specific interventions, establishing best conversion routes for biomass types was particularly favored by German and French respondents, significantly more so than in the UK and Spain. Matching feedstocks to conversion routes which gave the best conversion efficiency or value addition makes perfect sense but in situations where diversity of production increases competition between bio-based businesses for the same feedstocks, prices rise and competitiveness with fossil-derived or imported products may be further reduced.

Improving access to pilot facilities was deemed more of an issue for UK respondents than in other regions. In the UK, the Centre for Process Innovation (CPI), is the main

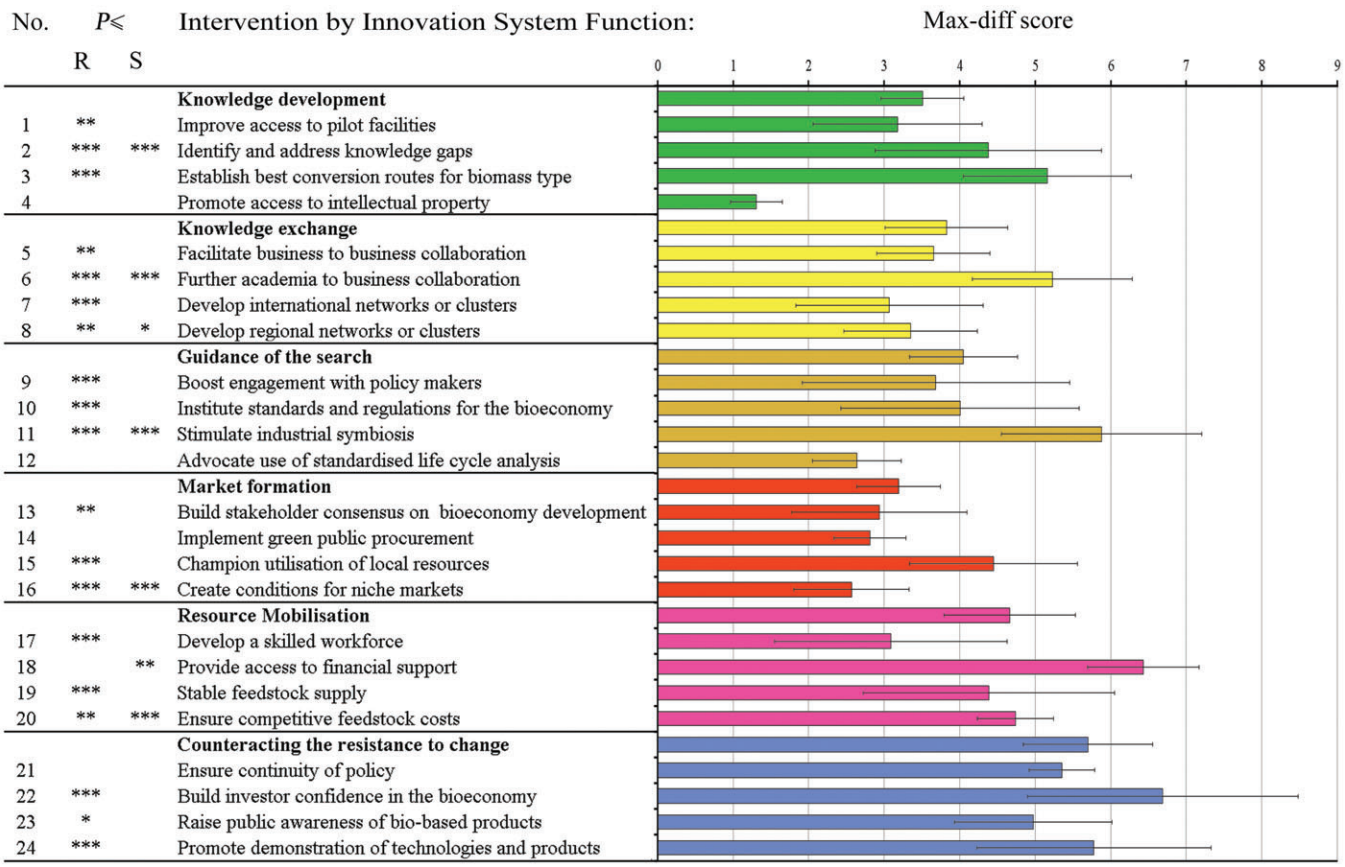

Figure 4. Overall mean response to the max-diff survey component from France, Germany, Italy, Spain and the UK presented by innovation system function and intervention. Error bars represent overall standard deviation of mean of region and stakeholder group; Significance of observed differences between regions (R) and stakeholder groups (S) is given as: P≤0.05, *; P≤0.01,**; P≤0.001; ***.

hub for industrial biotechnology business support and at least another four technology commercialization centers are available covering different aspects of bio-based product manufacture and technical development but the response suggests there may be either technology gaps or a lack of awareness of the pilot scale facilities currently available in the UK. However the need to identify, leverage and build upon EU capabilities for pilot and demonstration facilities was also a key recommendation of BIO-TIC.[15]

Knowledge exchange was heavily emphasized in responses to the Star Colibri consultation but featured less highly in further studies (Table 1.) which may suggest initiatives have successfully been put in place to address some of these knowledge transfer gaps. For example, at EU level emphasis has been placed on developing innovation partnerships through mechanisms such as Horizon 2020 and other programs which fall under the umbrella of the European Innovation Union.

Based on responses to this study, knowledge exchange remained a barrier of particular focus for Italian respondents who indicated greater need for academic-industry collaborations and emphasized the importance of establishing both regional and international networks and clusters. In follow-up consultation, the need for clusters was predominantly around utilization of residues arising from different farming systems, in effect placing greater emphasis on the start rather than the end of the biorefinery value chain. This is an interesting point which has implications for the wider bioeconomy regarding how new bio-based products and processes and those of traditional agriculture and forestry systems are delineated and how these actors can be more effectively brought together.

French respondents also placed considerable emphasis on academic-business and business-to-business collaborations. In France, a national strategy is ongoing which involved creation of part-subsidized 'competitiveness clusters' which has developed into an extensive network

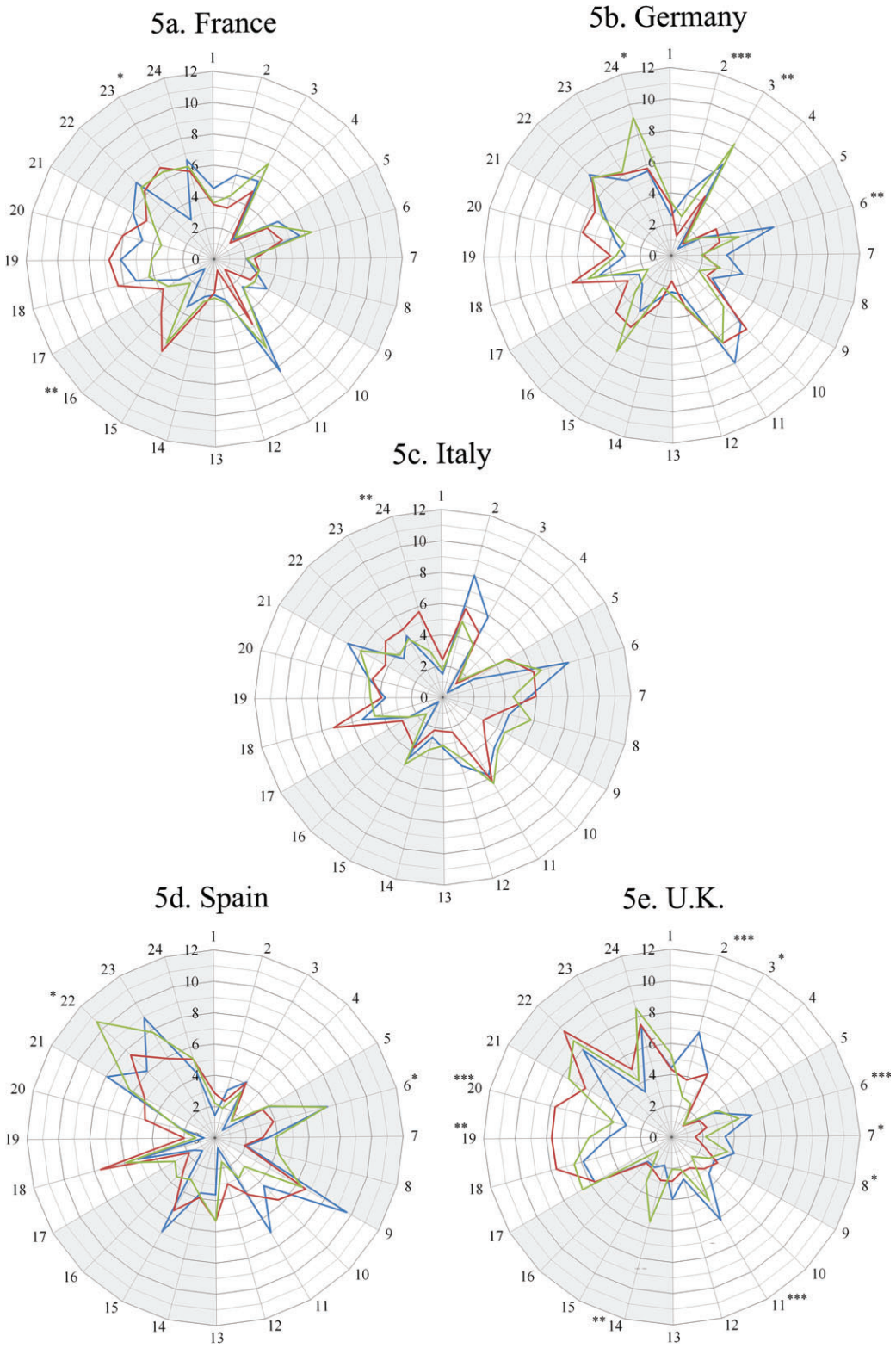

Figure 5. Difference in perceived importance of interventions between study regions and stakeholdergroups: Academic, Blue; Industry, Red; Policy, Green. Significant difference identified between stakeholders is indicated beside the corresponding intervention number as: P≤ 0.05, *; P≤0.01, 0.01; P≤0.001; ***. Shading differentiates innovation system function groups.

of (>7000) business partnerships coupled with research organizations and local authorities to drive innovation focused on specific topic areas, of which bio-based economy and green growth are a focus. These clusters have had considerable success and perhaps provide a template for similar development in other regions.

Barriers in relation to **the guidance of the search** function are activities or resources which give clarity and direction to development and innovation. This has a great influence in terms of the expectations of the involved actors within the system and how these are managed;[16] for example, through government commitments, national strategies, regulatory tools, or other clear messages or targets which give confidence and stimulate development.

Regional differences in responses to the interventions within this category were diverse (Fig. 4). Boosting engagement with policymakers was perceived as a much greater need in Spain than in other regions. This could be due to the fact that, at present, while there are bioeconomy related plans included in technology and waste management strategies, there is no specific national strategy for bioeconomy in Spain. However, a task force had been established to develop a national strategy at time of writing.

The need to institute more standards and regulations was considered particularly important to German respondents and to a lesser extent those from Italy and Spain. This was not considered as important to those from the UK and France. Differences between these results may also be due to differences in bio-product emphasis. The LMI report identified a clear need to balance legislation and policy between bioenergy and other bio-based product categories and also specified a need to harmonize certification and labeling schemes for bio-based products.[12]

Stimulating industrial symbiosis and creating circular economies to minimize waste and improve resource efficiency, was the intervention ranked most highly within this category. This was also a key recommendation of BIO-TIC but was not as prominent in previous consultations.[15] The need to stimulate industrial symbiosis was of particular importance to stakeholders from Germany, France, and Italy but of lesser importance to those from other study regions. One regional policy difference which may offer some explanation for this is that the UK has had a National Industrial Symbiosis Programme (NISP) in operation since 2005 which has built up an impressive track record and has been highlighted as an example of best practice. It has also recently been announced that a similar and related initiative , Programme National de Synergies Inter-Entreprises (PNSI), is being introduced across France.

Market formation was not perceived to be a significant barrier based on the responses received to this survey. It is interesting to note that no interventions were suggested for this function in either any of the previous consultation studies.[11, 12, 15] This lack of emphasis may reflect the focus on displacement of existing fossil-derived products with bio-based alternatives in well-developed markets. However, penetration of new products into existing markets may have been regarded as a separate issue. That said, championing the utilization of locally available resources, for example encouraging innovation through utilization of domestically sourced biomass feedstocks, was of great importance to all regions with the exception of the UK. There was also some consensus between regions regarding the importance of green public procurement; while it was not ranked amongst the highest, it was considered a beneficial intervention by all stakeholders across all regions.

Resource mobilization was ranked as the second highest barrier which required intervention based on survey responses. A high importance ranking of this function was likely as it included the need to mobilize feedstock and human and financial resources, all of which are critical factors to industry function. However, the relative importance of this barrier differed distinctly between regions and was exaggerated by the strength of the UK stakeholder response to this category, particular regarding the need to develop a skilled workforce which was significantly more important to UK respondents than those of all other regions (Table 2 and fig. 5e). The need to improve attractiveness of the bio-based sector to develop a strong European workforce in industrial biotechnology (IB) was also listed as a priority in both the Star Colibri and BIO-TIC studies (Table 2). The latter also emphasized the importance of improving opportunities for feedstock producers. This is an important consideration and a critical stakeholder group frequently absent from many consultations focused on IB and the development of 'new' bio-based products.[11,15]

The need for improved access to financial support was also commonly regarded as critical by stakeholders from most regions. In follow-up interviews, this financial support was predominantly required for scale-up rather than start-up of bio-based businesses which is also reflected in recommendations made in previous consultations.[11,12, 15]

The need to ensure a stable feedstock supply was more acutely felt by respondents from the UK and France but regarded as less of an issue in Spain than other regions. This may be due to the fact that use of industrial wastes and co-products were more a focus of the Spanish respondents whereas those from the UK and France cited conventional crops and crop residues as the main feedstocks used (Fig. 1)

but in the last few years both France (2014) and the UK (2015) have launched national strategies for utilization of wastes specifically as biorefinery feedstocks.

Counteracting the resistance to change was a clear priority of respondents from most regions. Resistance to change would be expected to be a major barrier, as the use of bio-based products is still largely perceived as an ethical choice linked to environmental awareness and concern regarding climate change. The foremost intervention required to address resistance to change was ensuring continuity of policy, this intervention was unanimously ranked by all stakeholders across all regions. This intervention is also deeply interconnected with the function of 'guidance of the search' where appropriate policy formulation is a critical factor. Ensuring a transparent and stable long-term policy framework was also a key recommendation of the BIO-TIC consultation study (Table 1).[15]

Building investor confidence in the bio-based economy and demonstration of technologies/products were also considered key interventions in responses to this study and feature highly in many others (Table 1.). Both these interventions were considered important to all regions in this study with the exception of Italy. Indeed the need to counteract the resistance to change, raise awareness, and demonstrate new technologies or products was significantly lower in Italian responses compared with those of other countries (Fig. 4). This could be the result of interventional policies already enacted in Italy such as the Biorefinery Decree (n139/2013) which simplified authorization procedures for the development of second- and third-generation biorefineries and the National Environmental Decree (2012) which ruled that carrier-bags have to be biodegradable or reusable which created increased demand for bio-plastics. As a result large-scale commercial developments have already been completed in Italy and more are underway. It is possible that these policy interventions have in some way already overcome areas of resistance to change in a way that other countries have not yet addressed to the same degree.

Summary of key points and recommendations

The main objective of this paper was to horizon-scan for regional differences with a view to focusing on areas of success and failure which could indicate best practices. The results obtained provide an overview of the key barriers and interventions as perceived by stakeholders active in bio-based sectors and major differences highlighted.

Where possible, suggestions have been made regarding situations where particular policy interventions would be most beneficial and where existing initiatives may already be having a positive influence which could suggest best practice. However, it was not possible to fully discuss and elucidate the great number of differences observed between and within specific regions which must be further scrutinized. One such related region-specific article has already been published which looks in more detail at the situation in the UK and makes a series of region specific policy recommendations.[26]

In further research, sectoral comparisons should also be performed in greater detail, and to have a really European overview on this matter, increased sample size would improve data resolution within regions, sectors, and value chains involved which could be more specifically directed at assessing specific effects of related policy.

The combined approach of innovation system functional framework and max-diff survey presented here is unprecedented and as an approach has considerable potential to be applied to wide variety of circumstances either independently or as an adjunct to full innovation system analyses. A particular strength is that this consultation survey approach could be developed to provide a more rapid and dynamic contemporary analysis of system functions, whereas conventional innovation systems analyses are restricted by the time taken to gather and analyse information retrospectively. For this reason, combination of the two approaches requires further investigation and discussion.

In summary, based on the interventions which overall were deemed to be the most beneficial, the following recommendations should be considered in order to build investor confidence and support growth in the European bio-based economy:

- Establish the most effective conversion routes for key biomass types.
- Stimulate industrial symbiosis at all points through the value chain.
- Actively promote and demonstrate new bio-based technologies and products.
- Improve provision of financial support particularly for scaling-up production.
- Continue to develop targeted public private partnerships using best-practice models
- Develop an inclusive, balanced and stable policy framework.

Conclusions

The paper identifies several interventions which, based on the responses of stakeholders active in the field, would help support and develop innovation in the European bio-based

economy. The study also highlightes several key areas of consensus and disparity between perceptions of academic, industry, and policy stakeholders and regions, some of which may be explained by recent policy interventions.

Utilization of innovation system functions to provide a framework for survey design was shown to have great potential, particularly when coupled with max-diff survey design. This methodology could be further developed and applied for both cross-sectional and longitudinal studies and is easily adaptable for multiregional and multisector studies.

Further research should be conducted to improve use of innovation system functional frameworks to provide a better understanding of the drivers and to enable policy-makers improved dialogue and clarity of focus to develop policy that best meets the needs and expectations of the stakeholders who are key to development of a new bio-based economy.

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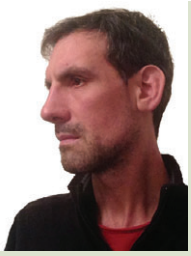

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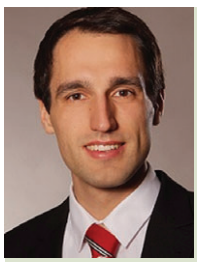

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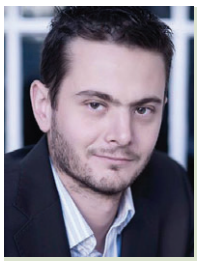

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